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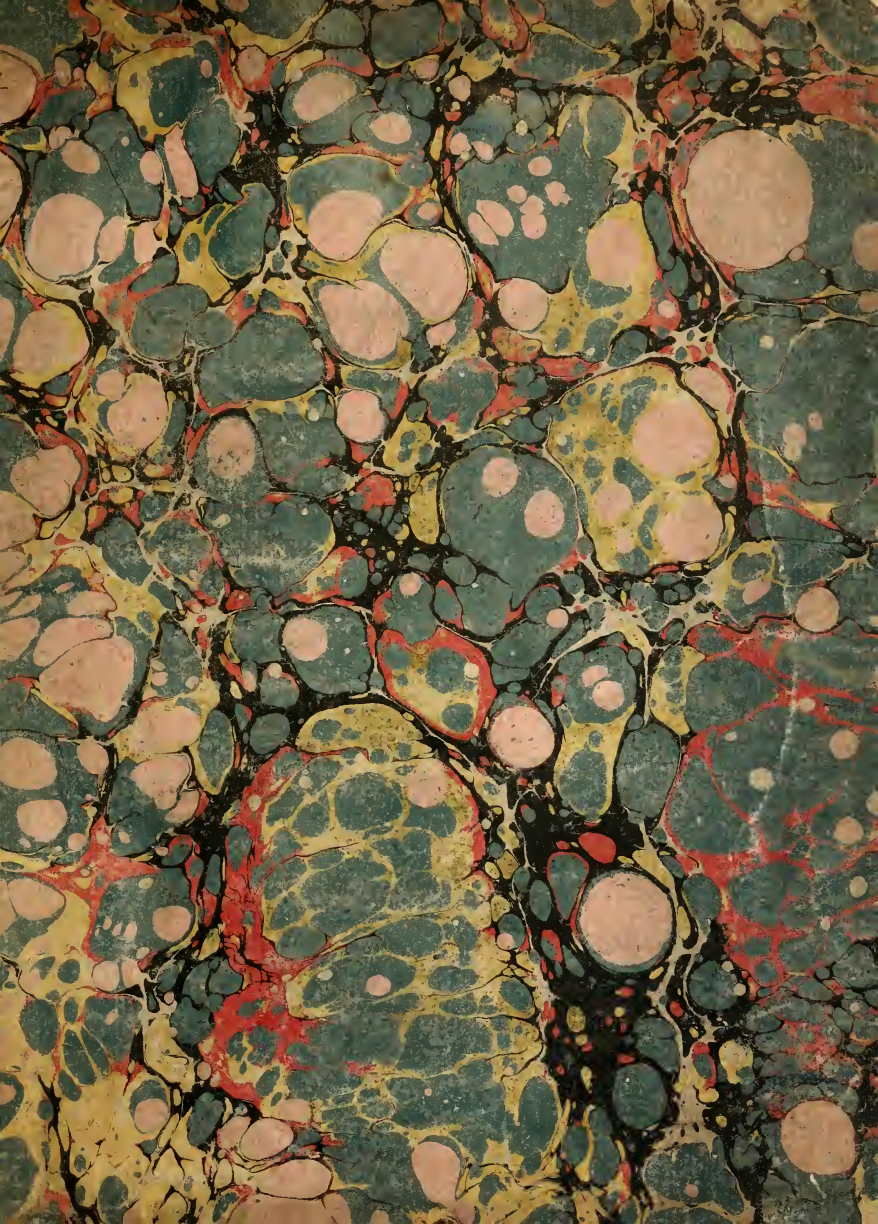


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HYDRAULIC AND NAUTICAL OBSERVATIONS

ON THE CURRENTS

IN THE ATLANTIC OCEAN,

FORMING AN HYPOTHETICAL THEOREM
FOR INVESTIGATION.

ADDRESSED TO NAVIGATORS

By GOVERNOR POWNALL. F.R.S. & F.S.A.

TO WHICH ARE ANNEXED SOME NOTES

By DR. FRANKLIN.

L O N D O N,

Printed for ROBERT SAYER, No. 53, FLEET-STREET.

MDCCLXXXVII,

THE writer of this paper begs leave to submit to the consideration of Navigators some observations on the Currents in the Atlantic Ocean, as applying to the use of Navigation.

The studies that he pursued, and the line of service in which he was employed in the early part of his life, led him, and enabled him, to make these observations.

The facts and effects which he states and describes, he throws out rather as matters of investigation, than as things proved, although some have been determined by observation, and others are of common notoriety: but it appears to him better to state them as matters which require, as they deserve, further and repeated observations in a more regular and more scientific course of experiment.

Some of these observations arose from his comparing notes (if he may so express himself) with several of his Majesty's Commissioned and Warrant Officers, in the frequent passages he hath had occasion to make across the Atlantic in his Majesty's ships: other remarks, and the observations thereon, have arisen from the reports of American masters of trading and * fishing vessels with whom he hath

* The period here referred to was when I was Governor of the Massachusetts Province, now State, the Island Nantucket being a county of that Province.

hath talked on the subject ; and * whom he found to understand the navigation of this Ocean better than the European masters seem to have done ; and who in consequence of that knowledge made shorter and better passages over it.

The observations are as follow : In like manner as the combined operation of *attraction* between the sun, moon, and earth, being uniform and permanent, produces an uniform and permanent effect in the general tides of the Ocean ; so the winds, where they are uniform and permanent, produce *by protrusion* Currents in the Ocean in like manner permanent and uniform.

The tide raised by attraction being (if I may so express it) a local elevated wave, which is preceded and followed in its progressive motion by a depression of the level, the sea is in a constant oscillation of tide and ebb. The Currents occasioned by the *protrusion* of the winds continue at all times flowing one way, either in the direction of the wind, or in a diverging lateral course, or in a reflexed recoiling Current, as the waters piled up against any obstruction find the means of running off, and descending from this forced elevation.

The winds between the tropicks, having a general course westward, protrude the waters of the Atlantic Ocean in the same direction, and cause a Current running always nearly in the same direction. Where this general current meets with land or islands

* The following note is from Dr. Franklin :

“ The Nantucket whalers being extremely well acquainted with the *Gulf stream*, its course, strength, and extent, by their constant practice of *whaling on the edges of it*, from their island quite down to the Bahamas ; a draught was made and caused to be engraven on the old chart at London in 1768, drawn from their information, and especially from that of Capt. Folger, and published for the benefit of navigation by B. Franklin.”

This was copied and printed at Paris by Mr. D’Chaumont.

But, as that was not perfectly exact, my old friend, on reading this Paper at Passy, Oct. 7, 1784, gave me some *notes*, which I have annexed to this Paper.

See also the note in page 15.

that

that obstruct its course, with rocky ground or sands that divert its course, or where it runs through channels which draw it into other directions, this general effect partakes of the operation of these secondary causes. This general Current in passing through the chain of the Carribbe and Bahama Islands, and amongst the cayos of the fame, is diverted and drawn from its general course in almost all directions. Where it is not interrupted or disturbed, it keeps its general course, as along the West-Indian sea through the Gulph of Mexico* to its bottom; and in the channel between Hispaniola, Cuba, and the cayos and islands of Bahama, to the Gulf of Florida. The main Current which runs directly West to the bottom of the Gulf of Mexico, being there opposed by the Continent, doth there pile up its waters to a very *elevated level*. These aggregated waters run off laterally, and descend down an inclined plain along the Coasts of Mexico, Louisiana, and Florida, and rounding the sable point of Florida rush into the Gulf of Florida. The Current, which runs N. W. through the old Bahama Channel, meets it at its embocheure, the current coming N. E. round the point from the Gulf of Mexico; and these in one combined Current set through the Gulf of Florida North Easterly, the lateral diverging partial currents, and something of a lee Current, excepted. From hence this Current, in a bending and expanding flow, sets North-Easterly along the coast of N. America to N. Latitude 41°, 20' or 30'.

† In the same manner, and from the like cause, the Currents in the Indian sea, Northward of the equinoctial line, have, during

* They cannot run off by the South of the Gulf of Mexico, because the winds and the general Current in the space between that Province and Hispaniola stop the current there.

† The four following paragraphs are a digression from the immediate purport of this paper; nor are the facts of that assured knowledge, in the mind of this writer, as they would be if collected by himself. He receives them as settled facts, and applies the description and explanation of them, which he here gives as collateral illustration, to the similar facts which are the immediate object of this paper.

the North-East Monsoon, a general Western course with the like divergings; and, during the S. W. Monsoon, have, with the like exceptions, a general Eastern course and direction.

To speak particularly: when the N. E. Monsoon blows, the Current impinging on the East Coasts of the Island Sumatra in an obtuse angle (as that line of Coast is North-Westerly, and South-Easterly) is reflexed off to the Northward, and sets North-Westerly through the Straits of Malacca, and thence in a circuitous expanding Current round the Bay of Bengal, along the Coasts from the East by North to the West, and on the Coast of Coromandel, running down an inclined plain South-Westerly, and thence rounding the point Comeroon, and the South point of the Island Ceylon, joins again the general Western current, which comes across the Ocean from the West Coast of Sumatra. Part of this general current continues its direct course across the Indian Sea, and part runs off laterally North-Westerly along the Malabar Coast; where it passes through the chain of Maldivas and Lakedivas Islands, it runs in all directions, as it is operated upon by secondary causes, as above referred to. It continues its general Western direction in a circuitous course round along the Coasts of, and across, this Indian Sea to the Western side; in passing the mouth of the Gulf of Persia, and that of the Red Sea, it runs continually, during that Monsoon, through their Straits up into that Gulf and that Sea. On the Western side of the Indian Sea running down an inclined plain, it sets South-Westerly along the Coasts of Africa, and through the inner passage between Africa and the Island Madagascar. On the Eastern side of this passage, that is, on the Western Coasts of Madagascar, a Northern Current, partly a lateral, and partly a lee Current, takes place.

In consequence of these Currents, and these winds during the N. E. Monsoon, and of the winds to the Southward of the line,
the

the Current included within the space between the Island Ceylon, the Island Sumatra, and the South parallel 5° , running round in an eddy, sets first West, and then returns East by the South.

The effects of the S. W. Monsoon are almost the reverse of this.

The Current, during this season, which runs between Africa and Madagascar, sets North on both sides of this inner passage; it holds the same Northerly course between Madagascar and Mauritius, and so continues Northerly in a circuitous course along the Coasts of Africa; then Easterly across the Arabian and Indian Coasts; and then, running down an inclined plain, sets South-Easterly along the Malabar Coast. During this Monsoon, the Current sets out of the Red Sea and Persian Gulf. Where this general Western Current crosses this Indian Sea in the latitude of the Maldivas Islands, and sets directly upon them, it rebounds, and, making an eddy round by the South, joins to the South of Ceylon, the general Eastern Current. These combined Currents, rounding the point Comaroor and the Island Ceylon, set in part directly across, and in part round, the Coasts of the Bay of Bengal in a circuitous course from West Northward to the East, and then down an inclined plain South on the Eastern side of the Bay, and in the same course set through the Straits of Malacca, and also South along the West Coast of Sumatra.

During this S. W. Monsoon, from the same causes as above assigned, the Currents, in the space included between Ceylon, Sumatra, and South parallel 5° , form an eddy running East, South, and round West.

These facts are matters of common notoriety; but this Paper quotes them as more particularly stated by Monsieur de Grenier, in his map* of the Currents in the Indian Seas, to the Northward of the Line.

* Published by Mr. Robert Sayer, of London.

After considering these facts compared in their causes and effects, this paper proceeds to offer to observation the like facts, appearing in like effects produced by like causes in the Atlantic Ocean.

The writer of this paper begs that, in the observations and reasoning which follow, he may not be considered as building up a theory without foundation: he thinks nothing can be more contrary to, and more obstructive of, real science than such visions: yet, on the other hand, where there are a number of dispersed facts, which, though not specifically defined in the form of experiment, are, however, *practically known*, so as to become capable of combination sufficient for use, he thinks the so far combining these facts, as to form an *Hypothetic Theorem* (not as a matter demonstrated, but as a subject of investigation), is exactly philosophical, and conformable to the strictest line of mathematical reasoning.

Under this predicament he begs to submit the following mode of reasoning on the Currents found in the Atlantic Ocean; as leading to *practical rules for the navigation* of that sea; and as a foundation for queries the investigation of which may be of the highest import to a decisive facility of the intercourse between Europe and America.

This Paper here takes up the Current of the Gulf Stream, as it sets along the New England coasts, where we before left it. It commences with facts actually observed. The Northern edge of this Current lies in the Meridian of the Island Nantucket, in N. Latitude * $38^{\circ} 30'$, and in the Meridian of George's Bank; its Northern edge is in North Latitude * 39° , where its course is E. N. E.

* These facts were in part confirmed, and in part corrected as they now stand, from a paper given to me, by my old friend Dr. Franklin, at Passy, Oct. 7, 1784.

In the Meridian of the Isle of Sable its Northern edge is in North Latitude* $41^{\circ} 20'$ or $30'$; and here its course is E. S. E. and S. E. by E. The Southern is not so decidedly marked or known†.

This Paper will now, as a leading illustration by analogy, not as matter of proof, suppose for a moment an imaginary line of Coast crossing the Atlantic from Nova Scotia to the Canaries. That supposed; he ventures to assert, on the analogy of facts stated above, respecting the Indian Seas; that this Atlantic Current, thus brought according to actual observation to North Latitude $41^{\circ} 30'$, and there setting in an E. S. E. course, would continue its course along this supposed Coast, E. S. E. untill it had crossed the Atlantic, and approached the African Coast.

Quitting supposition, this paper next proceeds to state facts.

1. If two lines are drawn across the Atlantic Ocean, one from the Southernmost part of the Canaries to Halifax, in Nova Scotia; the other from the Northernmost part of the Madeiras, by the Azores to Cape Race in Newfoundland; the space contained within these lines, though not (as above supposed) a line of Coast, will yet be found *in fact* and truth to be a broken line of islands, rocks, breakers, and banks. Now as these visible rocks must have their base on some elevated ground, as the breakers must be occasioned by some sunken rocks or elevated ground; and as the banks must shoal off gradually, howsoever steep; the ground within this space

* These facts were in part confirmed, and in part corrected as they now stand, from a paper given to me, by my old friend Dr. Franklin, at Passy, Oct. 7, 1784.

† See the Chart of the Atlantic Ocean printed and published by Mr. R. Sayer, 1787; in which the reader will find this Current marked by a dark shade, very exact as to the Northern Latitudes of the edges of it; and he will observe that this shade is lighter and lighter as the stream expands itself, and grows weaker so as almost to vanish as it approaches the African Coast. The under or Southern edge is engraved also with an indecisive line.

thus crossing the Atlantic is in strict fact an elevated, though broken line of ground.

2. Now the Current to the Southward of this space, so far as it hath been observed, hath been generally found in fact setting along this line, in a course between the East and South.

3. Where this line is broken by the intervention of deep channels, or is discontinued by intervals of sea, without soundings; so far must the general effect of the Current running along a line of Coast, as above supposed, not take place; and, in those channels and intervals of deep sea, Currents will diverge off from this general course East, or perhaps North, especially when the winds blow strong from the Southern board. Now the fact is, as the writer's information stands, that a Current sets off from the general course, and runs East, between the Islands Pico, and St. Michael of the Azores. There is also a Current diverges off from the general course, and sets East, between the Madeiras and the Canaries, directly in and upon the African Coast. The general Current however to the Southward of the Canaries holds its general Southeasterly course, and sets in, generally speaking, in that direction, upon the African Coasts in those parts.

Over and above the protrusion of the tropical, or trade winds, which are the first and original cause of these general Currents in the Atlantic Ocean, as above described, the level of the Ocean on the African Coast, between the tropics, being depressed by the evacuation of waters continually blown and running off from that Coast, and protruded Westward, the protruded Current which we have traced across the Atlantic, setting in and upon the African Coast, must thence run down an inclined plain towards this depressed level, along those Coasts (as to their general course) South-Easterly, whatever may be the temporary and local deviations from this general course, occasioned by local and temporary circumstances

cumstances of particular coasts and seasons. Now this state of the matter compared by its causes and in its effects is the actual fact*.

This Current thus revolving in an orbit (which, speaking generally, may be said to be a defined orbit) round the Atlantic Ocean in a continual circulation; it is conformable to the laws of Hydraulics that there should be, in the space included within the inner edges of this orbit, an eddy, into which all floating substances, such as wood and weeds, which fall into the general Current, shall be finally absorbed. Now the fact is, that weeds called the Saragosa weeds, as also the Gulf weeds, have been observed as found at certain and ascertained latitudes and longitudes, within the area of the orbit of this general Current, and nearly on what may be supposed the inner edge thereof; as in N. Latitude 34° West Longitude from London 41 ; again, in N. Latitude 33° West Longitude 30° ; the breadth of the space within which these weeds

* The writer of this paper speaks in the text of the fact only. May he be permitted in this note to attempt an explanation of this curvilinear course? The protruding force of the tropical winds acting nearly always in the same direction, and piling the waters up against the Western Coasts of the Gulf of Mexico, whence they run off, he considers as the projectile force. He must look for another diagonal force, acting either externally or internally upon this in all points, so as to form the course into a curvilinear one. He finds an external repellant diagonal force as follows acting at all points, but in different points, with a different direction as to the angle of impact, so that the course, although curvilinear, is not an uniform curve. The Gulf stream runs laterally along the Coast of N. America, thus traversing laterally an inclined plain, whose general and almost uniform slope is to the S. E. hence there acts diagonally a repellent or reflecting force in a N. W. direction on this stream, as it is running from the Coasts of Florida to Nantucket Shoals, and St. George's Bank: and therefore gives it an almost uniform curvature thus far. In passing by Cape Sable Shoals, and Sable Island Banks, it is reflected by an inclined plain, sloping almost South; and therefore bent into a greater curvature running E. N. E. passing hence it meets another inclined plain, the Banks of Newfoundland lying still more South, which impell it into an E. S. E. direction, which course it keeps between these Banks and Canaries, along the Southern side of the broken elevated ground above described.

are here found is about $2^{\circ} 45'$; again, in W. Longitude 27° . The Northern boundary in which these weeds are here found is N. Latitude 34° , and the Southern boundary 19° . Now whether the space, in which those floating substances have been regularly found, partakes of the nature of an eddy, or is the reflow of a lee Current on the inner edges of the main circulating Current, has never been observed, much less examined with that attention and accuracy which a circumstance so important to the navigation of the Atlantic Ocean deserves. The first navigators to the West Indies and America observed, and followed, the general Currents out and home; those who followed them followed mechanically on authority: and, even to the days of this enlightened age, very few, if any, observations have been made as to the eddy or lee Currents in the great space of ocean or area included within this orbit, at least none as yet applicable to use and practice.

Although there are not in the Northern parts of the Atlantic Ocean any settled Monsoon, or any trade winds, as between the tropics; yet to the Northward of the space above described a general Eastern Current takes place, running along the North boundary of this space, to the East Southerly, across the Atlantic, towards the Coasts of Europe, and sets continually through the Straits into the Mediterranean Sea; just as the Current in the Indian Sea sets during the N. E. Monsoon, into the Gulf of Persia, and through the Straits of Bab-el-mandel into the Red Sea. Various operations and combinations of winds, and various circumstances of Banks, and elevated ground in this Northern part of the Atlantic, may be assigned as causes of this effect. These are not yet sufficiently explored, even not so much as to admit of a theoretic combination. The matter, however, is fact, and of common notoriety, as is the fact that the passage from America to Europe is at least one third shorter than the passage from Europe to America. It is so much

fo, that it is a common expreffion amongst the American navigators, that *the courfe is down hill all the way home* (as they ufed to call England). The prevalence of the Western and North-Western winds on the American Coasts; the prevalence of the Northern and North-Eastern winds on the Northern Coasts of Europe, combining with the effect of elevated ground to the Westward of the British Isles; and the banks of Newfoundland on the Coasts of America; may fairly be propofed as an experimental theorem, for investigation of the general matter. The temporary East and South-East winds on the Coast of America, and the West and South-West winds on thofe of the Northern Parts of Europe, are caufes of local and temporary deviations from this general courfe; as, for one instance, when the South-Western winds have prevailed for any long time about the Equinoxes, and fet in ftrong upon the Northern Coasts of Europe, and veer round West and North, they pile up an aggregate elevated body of waters on the Coasts of Norway *. If this veering change of the wind happens about the time of the full, or new Moon, and about the time of high water on the Coast of Norway, this aggregate body of waters, added to the fpring tides, pour down into the German Ocean fuch an inundation of waters as create thofe *high raging tides* on the Dutch, Flemish, and British Coasts, which fo much furmount all ordinary defences raifed againft them. If, under this coincidence of the afore-named circumftances, the wind fhould ftill more veer round with the Sun, and come to East, juft upon the fetting of the tide into the German Ocean (which hath repeatedly happened), this inundation of thefe *high raging tides* will be blown over to the British Coast, and protruded through the Channel on the West fide of

* The circumftances here ftated are facts known on obfervation, as far back as the memory of-man, not only by the Harbour Pilots of thofe Coasts, but by the inhabitants living thereon.

the Doggers Bank, upon the English Coasts, in such a swollen and irresistible Current, as hath at times, exceeding all bounds of defence, done so much mischief to, and brought such ruin on, the maritime parts of the country, where the spring tides occasioned by the Moon do actually coincide, as above stated, with the *tide formed by protrusion* of the winds : they then come in as the highest possible flood (*cæteris paribus*) when they do not, although combined, actually coincide in the same point of time : then is there always observed to be two tides succeeding each other at the space of half an hour, and so forth ; that is to say, the Moon-tide, at or near its usual time, and the great protruded wind-tide half an hour, an hour, and so forth, before or after.

This observation of the manner in which the effect of protrusion of the winds, as well as attraction, operates on the Currents and tides of this German sea, the writer of this paper here incidentally makes, in order to suggest to the Landholders of these parts the necessity there is of giving attention to these circumstances, and their combination, and of taking preparatory precaution ; when this combination is, in event, to obviate and guard off many of those evils which they have repeatedly suffered, at least to guard them against being surprized, although perhaps adequate defence may not be in their power.

He does not here mention this as a precise, or compleat explanation of this dreadful phenomenon. He is engaged in a course of inquiry after every particular of the facts, their circumstance, and combination, as far as they may be supposed to form the cause and create the effect of these *high raging tides* in the German Ocean ; in order at least to ascertain the prognostics with a sufficient degree of certainty to the purposes of precaution.

But to return : one observation still remains respecting the Currents, which run thus East-Southerly on the North side, and on the
South

South side of the aforementioned space, across the Atlantic, the investigation of which may be of the greatest use to the navigation of those parts. Howsoever general the South-Eastern course of these Currents may be; yet, as the wind happens to be on the Northern or Southern board, the Currents of the Seas and Channels within this space will continually vary in all directions, according as the protrusion of these winds operate, the one way or the other, and always more or less, as other variable causes conspire to pile up the waters on the one side or the other of it.

Having stated as above, not a theory without foundation, or a matter as proved, but an hypothetical theorem for investigation on experiment, the writer, instead of drawing conclusions, will close his observations (after pointing out some instances of the use of them) by proposing some queries as matters well worthy of trial and enquiry *. *These queries should be considered in a separate paper.*

Skilfull navigators, who have acquired a knowledge of the extent to which the Northern edge of the Gulf Stream reaches on the New England Coast, have learnt in their voyages to New England, New York, or Pennsylvania, to pass the Banks of Newfoundland in about 44° or 45' N. Latitude, to sail thence, in a course between the Northern edge of the Gulf Stream as above described, and the shoals and Banks of Sable Island, George's Bank, and Nantucket, by which they make better and quicker passages from England to America.

By an examination of the Currents in the higher latitudes of the Northern parts of the Atlantic, and of their course along the Coasts of Greenland, and the Ekimaux shores, if they should prove such as the reasoning in this paper leads to, a much quicker passage yet may be found.

* "The Nantucket Captains of Ships, who are acquainted with this stream, make their voyages from England to Boston in as short a time generally as others take in going from Boston to England, viz. from 20 to 30 days." Benj. Franklin.

By a particular and still more accurate examination * of the Northern and Southern edge of the Gulf Stream, of the variation of these circumstances, as winds and seasons vary; an experimental ascertaining what, where, and of what nature, the lee Currents on the edges both inner and outer of the Gulf Stream are; great facilities and assistance must be derived to navigation. The knowledge of this would lead to the ascertaining the eddies or other partial Currents in the great space of Ocean included within the great circulating Current. The knowledge of the Western edge of the Current which sets South along the Coasts of Africa, and of all its variations, as also of the lee Currents upon that edge, would be of essential use in navigating to (and perhaps from) the West Indies. A practical knowledge of the variable Currents, and how they vary under operation of various causes, in the space aforementioned, as running across the Atlantic might be of great benefit in forwarding a quick

* "A stranger may know when he is in the Gulf Stream by the warmth of the water; the warmth of that water, which the stream forms, being much greater than the warmth of the water on each side of it. If the navigator is bound to the Westward, he should cross the stream, and get out of it as soon as possible; whereas, if you get into the Gulf Stream, you will be retarded by it at the rate of 60 or 70 miles a day. Benj. Franklin.

"I have, in the course of my passages to and from America, made several experiments with the thermometer on the warmth of the water within the Gulf Stream; and of the difference at the edges.

"The Nantucket Whalers are so well acquainted with the course of this stream, *on the edges of which they fish*, that, if they do not find their game on one edge, they cross the stream, and try the opposite edge." Benj. Franklin.

Observations and experiments made by Dr. Blagden, in his passage out and home across the Atlantic Ocean, in the year 1776, coincide with what had been before observed so far as respects the warmth of the water within the Gulf Stream. They go also further as to the different degrees of warmth in lower or higher latitudes. The writer of this paper is glad to profit of such respectable testimony, so far as it goes to the degrees of warmth, known indeed some years before. This paper of Dr. Blagden was laid before the Royal Society, April 1781; and is printed in the Transactions of that Society.

passage

passage from America, perhaps in shortening the passage thither in winter. Various other uses of this enquiry might be pointed out, but to have marked that this hypothetical theorem is not without its use is sufficient.

Queries.—To what extent North do the Currents immediately under the trade winds reach, and how do they vary in the extent, and in the direction of their course, towards the extremities in different seasons of the year?

Is there any lee Current or eddy, and, if so, of what nature and direction is it at these edges?

What are the eddies or lee Currents of the Gulf Stream in the Gulf of Florida?

In what manner, and to what extent does the Gulf Stream (in general, and under various winds) diverge at its passing out of that Gulf?

At what distances in various parts doth it run from the Coasts of N. America?

What, and of what sorts, in different seasons, and under different winds, and different periods of the tides, are the lee Currents between the Gulf Stream, and the Coasts of N. America?

What Currents, diverging off from the general Current, between the Banks of Newfoundland and the Canaries, are there? What are the Circumstances of these divergings; and how do they vary in various seasons, and under various winds?

What are the courses of the variable Currents in the aforesaid parts? And what appears to be the circumstances at least attending, if not caused by them?

Is there any general course of Currents, or what are the partial ones, which take place in the great space of the Atlantic Ocean, included within the area of the general circulating Current? Do the Currents within this space run round in an eddy, in the direction of the circulating general Current; or do they run in the reversed direction as a lee Current?

